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Linking Enhanced Resting-State Brain Connectivity with the Benefit of Desirable Difficulty to Motor Learning: A Functional Magnetic Resonance Imaging Study

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Abstract : Practicing motor tasks arranged in an interleaved order (interleaved practice, or IP) generally leads to better learning than practicing tasks in a repetitive order (repetitive practice, or RP), an example of how desirable difficulty during practice benefits learning. Greater difficulty during practice, e.g. IP, is associated with greater brain activity measured by higher blood-oxygen-level dependent (BOLD) signal in functional magnetic resonance imaging (fMRI) in the sensorimotor areas of the brain. In this study resting-state fMRI was applied to investigate whether increase in resting-state brain connectivity immediately after practice predicts the benefit of desirable difficulty to motor learning. 26 healthy adults (11M/15F, age = 23.3±1.3 years) practiced two sets of three sequences arranged in a repetitive or an interleaved order over 2 days, followed by a retention test on Day 5 to evaluate learning. On each practice day, fMRI data were acquired in a resting state after practice. The resting-state fMRI data was decomposed using a group-level spatial independent component analysis (ICA), yielding 9 independent components (IC) matched to the precuneus network, primary visual networks (two ICs, denoted by I and II respectively), sensorimotor networks (two ICs, denoted by I and II respectively), the right and the left frontoparietal networks, occipito-temporal network, and the frontal network. A weighted resting-state functional connectivity (wRSFC) was then defined to incorporate information from within- and between-network brain connectivity. The within-network functional connectivity between a voxel and an IC was gauged by a z-score derived from the Fisher transformation of the IC map. The between-network connectivity was derived from the cross-correlation of time courses across all possible pairs of ICs, leading to a symmetric nc x nc matrix of cross-correlation coefficients, denoted by $C = (p_{ij})$. Here p_{ij} is the extremum of cross-correlation between ICs i and j; nc = 9 is the number of ICs. This component-wise cross-correlation matrix C was then projected to the voxel space, with the weights for each voxel set to the z-score that represents the above within-network functional connectivity. The wRSFC map incorporates the global characteristics of brain networks measured by the between-network connectivity, and the spatial information contained in the IC maps measured by the within-network connectivity. Pearson correlation analysis revealed that greater IP-minus-RP difference in wRSFC was positively correlated with the RP-minus-IP difference in the response time on Day 5, particularly in brain regions crucial for motor learning, such as the right dorsolateral prefrontal cortex (DLPFC), and the right premotor and supplementary motor cortices. This indicates that enhanced resting brain connectivity during the early phase of memory consolidation is associated with enhanced learning following interleaved practice, and as such wRSFC could be applied as a biomarker that measures the beneficial effects of desirable difficulty on motor sequence learning.

Keywords : desirable difficulty, functional magnetic resonance imaging, independent component analysis, resting-state networks
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